# SHEAR RESPONSE OF GLASS FIBER REINFORCED POLYMER AND POLYPROPYLENE RETROFITTED MASONRY WALLS SYSTEM

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**ABSTRACT**: Seismic retrofitting of unreinforced masonry structures in earthquake prone areas using cost effective and high performance materials is one of recent challenges which have attracted the attentions of many researchers worldwide. In this study, stress strain characteristics of FRP and FRP+PP-band retrofitted masonry wallets are studied under diagonal compression test. This study helps to quantify the amount of strain transferred from brick surface to the FRP. FRP can increase initial shear strength but exhibits a brittle failure. In spite of high cost and brittle failure, high tensile strength of FRP has made it a popular material. While PP-band retrofitted method do not affect initial shear strength but significantly increases the deformation and energy dissipation capacities of masonry structure at rate of very low cost. Whereas the FRP+PP-band composite, increases not only the initial strength but also deformation and energy dissipation capacities of masonry wall system. Diagonal compression test is carried out on a non-retrofitted, PP-band retrofitted, FRP retrofitted and one FRP+PP-band retrofitted masonry wallet. 45o strain rosettes are applied on FRP and FRP+PP-band retrofitted masonry wallet on brick and FRP surface in order to evaluate the complete state of normal and shear strains and stresses.

**Key Words**: Seismic retrofitting, Fiber Reinforced Polymer, Composite, Masonry, Polypropylene

## INTRODUCTION

Masonry is worldwide famous material because of its local availability and minimum cost of construction. Masonry contributes a biggest number of houses in world building inventory. In the past, masonry structures were rarely designed for seismic loadings. Some of the recent earthquakes in Bam Iran, 2003, Kashmir Pakistan, 2005 and Wenchuan China, 2008 have exposed the vulnerability of masonry structures against earthquakes. In earthquake prone regions of developing countries, most of the existing masonry structures are still at high level of risks. Many different researchers have proposed different retrofitting and strengthening methods each method has its own advantages and disadvantages. Adding steel or concrete frames, applying thick and strong pilasters, shotcreting and applying ferrocement to the wall surface are some of the retrofitting methods. Most of these methods are time consuming, add mass and reduces clear spacing [J.M. Gilstrap et al., 1998]. FRP retrofitting has also become popular in the last two decades. Initially, FRP was used for concrete and later on its application was further increased on masonry structures. Figure 1 shows some of the experiments conducted by different researchers in order to determine the in plane behavior of FRP for different FRP retrofitting procedures. FRP application was easy; fast and also do not require skilled labor.

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Different researchers tried different application procedures and found that FRP can significantly increase the initial shear strength but the final failure of masonry was highly brittle. FRP has overcome the problem of difficult application procedures with less retrofitting time but at the rate of very high retrofitting cost. In this regard Kimiro Meguro and Paola Mayorca have developed a new PP-band retrofitting method [Meguro and Mayorca, 2003]. PP-band retrofitting method uses polypropylene band. It is very cheap and locally available material. Because of its local applicability, easy applicability and social acceptability, PP-band retrofitting method is one of the cheapest retrofitting techniques. PP-band retrofitting technique has been used for retrofitting of masonry and non-engineered houses in Indonesia, Nepal and in some parts of Pakistan. Figure 2 shows the application of PP-band over a masonry house in Kashmir, Pakistan after 2005 Kashmir Earthquake. FRP can increase the initial strength but it is a brittle and costly material. But, PP- band cannot increase the strength but can hold the wall system for a much bigger ground motion without collapse. PP-band hold the masonry wall system and give deformation capacity and energy dissipation capacity to the masonry wall system [Meguro et al., 2008].

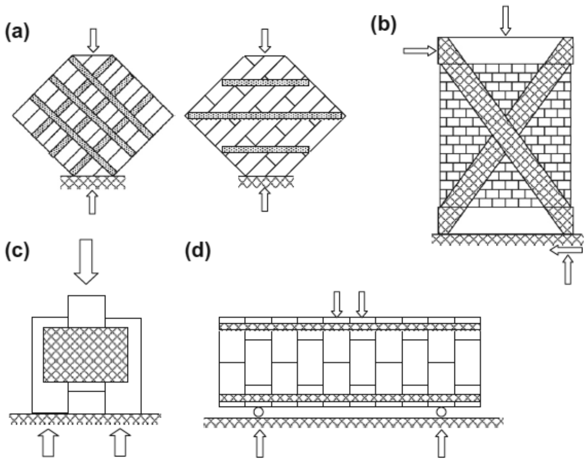


**Figure 1**. Different in-plane tests configurations utilized to investigate the in-plane response of reinforced wallets and specimens ((a) Valluzzi et al. (b) ElGawady et al, (c) Eshani and Saadatmanesh , (d) Triantafillou, P. Roca et al.)

**Figure 2**. Field Application of PP-band retrofitting technique to a sample masonry house in Kashmir, 2005

## RESEARCH OBJECTIVES

In current research, stress strain characteristics of a new proposed composite retrofitting material are assessed. This composite material consists of Glass Fiber Reinforced polymer and PP-band. For efficient utilization of FRP and PP-band, both of these materials are applied in a specific way to the masonry structure. For most of the researchers, it is always the point of concern to transfer the maximum amount of strain from the brick to the FRP for better utilization of FRP strength. In this study, four types of masonry wallets are tested. Out of four types, one is non-retrofitted (URM), one is PP-band retrofitted and one is FRP+PP-band retrofitted masonry wallet. In case of FRP and FRP+PP-band retrofitted masonry wallet, a 45o degree strain rosette is used to measure the strains on FRP and brick surface. In order to plot the stress strain curves of all types of masonry wallets a diagonal compression test is carried on all type of masonry wallets.

## EXPERIMENTAL PROGRAM

### *Materials*

Masonry materials are selected based upon the masonry construction in most of the developing countries. In order to construct the wallets at 1-4 scale, specially made clay burnt bricks of 75mm x 50mm x 38mm bricks are used. Bricks were soaked in water before construction of masonry wallet. Bricks were laid in cement lime mortar with weight mixed proportion (140g: 1110g: 2800g) of cement, lime and sand respectively. Mortar mixed is selected to replicate the decayed mortar conditions used in most parts of developing countries. Compression test is carried out on bricks and 50mm x50mm x 50mm mortar cubes according to ASTM C-67 and ASTM C-109. Bricks have shown an average compressive strength of 26.10 MPa. Whereas average compressive strength of mortar cubes is 1.16 MPa. Shear test, bond test and compression test is also carried out on masonry prisms. These masonry prisms were made using 5mm mortar thickness between the bricks. Brick triplets were made to measure the shear strength of mortar. The average shear strength of brick triplets was found to be 0.20 MPa. Biaxial type of GFRP is used with a fabric thickness of 0.5mm. Dimensions of PP-band are 6mm x 0.3mm. In order to determine the properties or GFRP and PP-band, tension test are carried out on one GFRP and 3 PP-band samples. Figure 3 shows the stress strain curve of PP-band and GFRP. GFRP has shown a very high tensile strength of 490 MPa with a failure strain of 2.7%. On the other hand, PP-band has shown relatively low tensile strength with an average value of 245 MPa but PP-band has shown a fairly long deformation capacity and has reached to a failure strain of 12.3%. E-250 epoxy bond is used to apply the GFRP over the surface of masonry wallet. Whereas PP-band is applied with the help of out of plane connectors provided at certain locations.

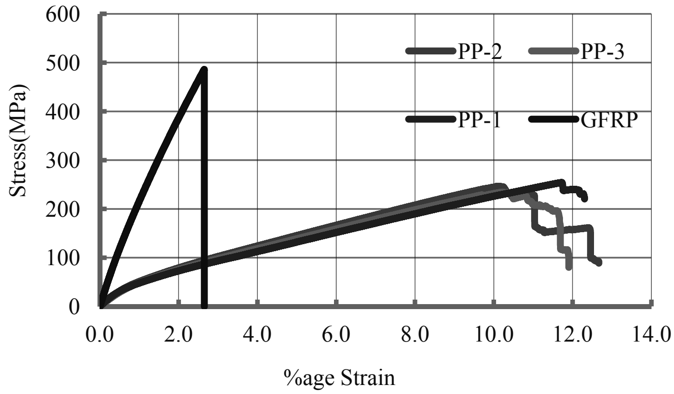


**Figure 3**. Stress strain curves of Glass Fiber Reinforced Polymers FRP and Polypropylene band

***Experimental Setup***

In current research, four types of masonry wallets are tested, one is non-retrofitted (URM), one is PP-band retrofitted, one is GFRP retrofitted and one GFRP+PP-band retrofitted wallet. All wallets were constructed using same constituent material and cured for 28 days before testing under same environmental conditions. Figure 4 shows the details of GFRP+PP-band retrofitted masonry wallet. All wallets have dimensions of 290mm x 280mm x 50mm.

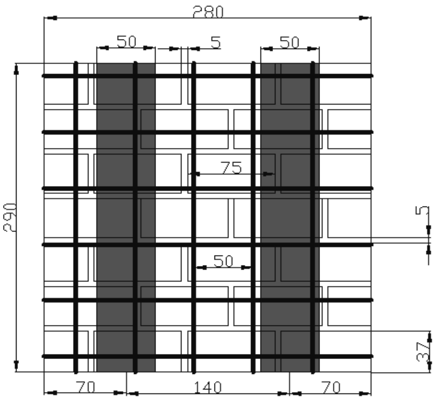


**Figure 4.** Details of GFRP+PP-band retrofitted masonry wallet

Wallet is tested under a static displacement control system. Response of wallet is measured in term of load and vertical displacement (ΔV) and horizontal displacement (ΔH). For displacement response measurement, two different type of test setup are used. High power lasers are used to measure the in plane horizontal deformation for URM and PP-band retrofitted masonry wallets. In case of FRP and FRP+PP-band retrofitted masonry wallet case two LDTV displacement transducers with 500×10-6/mm sensitivity are used. Six strain gauges are also used on each GFRP and GFRP+PP-band retrofitted wallet. Strain gauges at an angle of 45$^o$ from each other are pasted using CN bond after application of PS bond over the brick surface whereas 3 strain gauges are directly applied over the GFRP surface using CN bond after rubbing the GFRP surface using a sand paper. In all masonry wallets, initial loading rate is kept equal to 0.15KN/mm up to the initial failure. In case of PP-band retrofitted and GFRP+PP-band retrofitted masonry wallets a loading rate of 1.00mm/min is used. PP-band is connected at 40mm from each corner of wallet. PP-band and FRP is applied on both faces of masonry wallet.

Shear stress and shear strain developed can be computed by the following equation (1) and (2).

$$\mathrm{v} = \frac{P\cos\alpha}{((L+W)/2)t} \quad (1)$$

$$\gamma = \frac{(\Delta H+\Delta V)}{\sqrt{L^2+W^2}} \quad (2)$$

Where P = load applied, α = angle between the load and wallet top surface, L = length of wallet, W = height of wall, t = thickness of wall, ΔV = vertical deformation and ΔH = horizontal deformation.

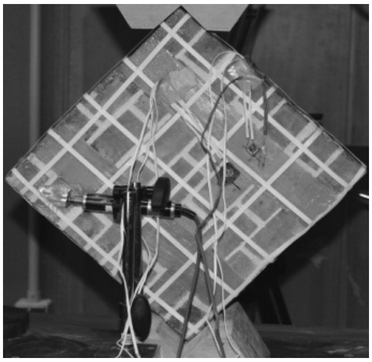

**Figure 5.** Experimental setup of a GFRP+PP-band retrofitted masonry wallet

## RESULTS AND DISCUSSION

### *Stress Strain Curve of Non-Retrofitted Masonry Wallet*

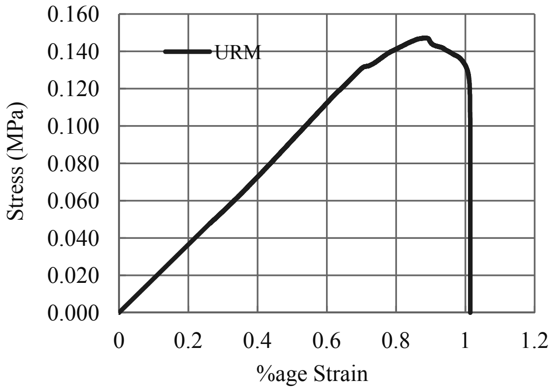


**Figure 6**. Stress strain curves of non-retrofitted masonry wallet

Figure 6 shows the stress strain curve of URM masonry wallet. Wallet has shown a peak stress of 0.144 MPa at a failure strain of almost 1%. URM wallet has shown a fairly linear behavior up to 0.6% strain. Failure of masonry wallet is shown in Figure 7.

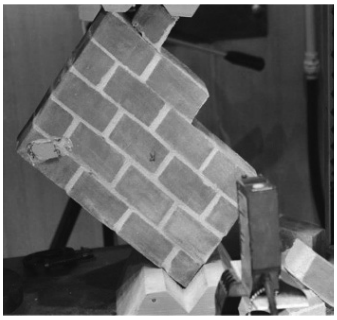

**Figure 7**. Failure Pattern of non-retrofitted masonry wallet

***Stress Strain Curve of PP-band Retrofitted Masonry Wallet***

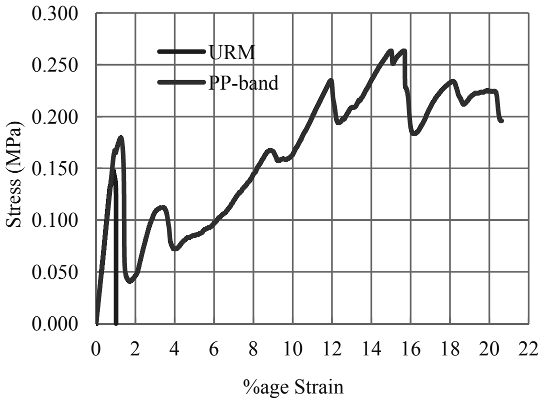


**Figure 8**. Stress strain curves of non-retrofitted and PP-band masonry wallet

Stress strain curve of URM and PP-band retrofitted masonry wallets are shown in Figure 8. URM and PP-band retrofitted masonry wallet has shown similar initial stiffness and peak load. In case of PP-band retrofitted masonry wallet, after the initial peak wallet again start taking load due to holding and confining effect provided by the PP-band. After the %age strain of 10, the wallet has shown a stress value which is greater than the initial peak strength of URM. PP-band retrofitted has shown a very high %age strain which indicates a very high ductility and deformation capacity of masonry wallet. Failure pattern of masonry wallet is shown in Figure 9.

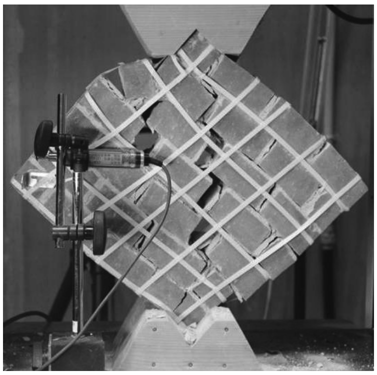

**Figure 9**. Failure Pattern of PP-band retrofitted masonry wallet

***Stress Strain Curve of GFRP Retrofitted Masonry Wallet***

Figure 10 shows the stress strain curve of URM, PP-band retrofitted and GFRP retrofitted masonry wallet. GFRP has increase the initial shear strength of URM and PP-band retrofitted masonry wallet from 0.17 MPa to 0.81MPa. But, failure strain of GFRP retrofitted masonry wallet was found to be only 4%. Final failure of GFRP retrofitted wallet was also brittle and failure was initiated due to debonding of GFRP from the wallet surface. Figure 11 shows the failure of masonry wallet due to detachment of GFRP from the wallet surface.

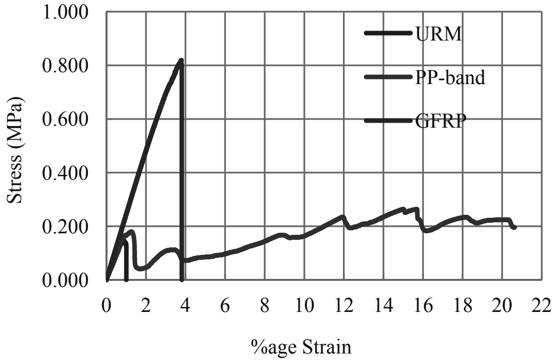


**Figure 10**. Stress strain curves of non-retrofitted, PP-band retrofitted and GFRP retrofitted masonry wallet

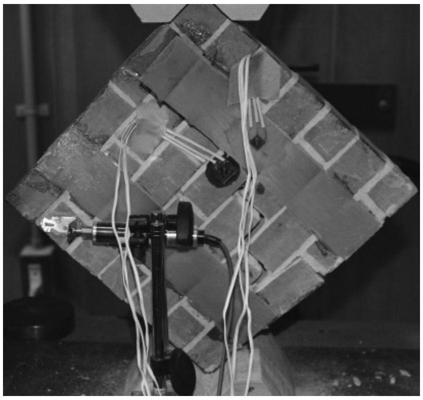

**Figure 11**. Failure Pattern of GFRP retrofitted masonry wallet

***Stress Strain Curve of GFRP+PP-band Retrofitted Masonry Wallet***

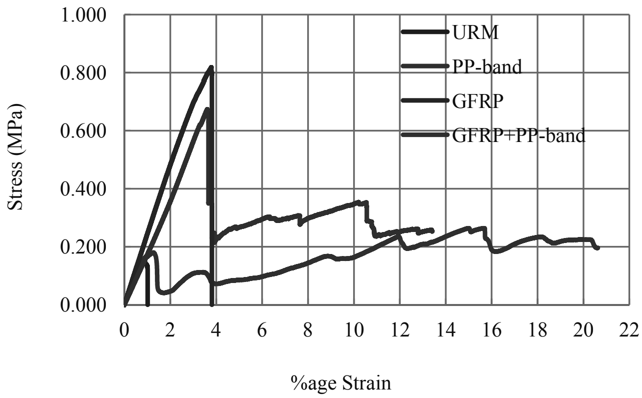


**Figure 12**. Stress strain curves of non-retrofitted, PP-band retrofitted, GFRP and GFRP+PP-band retrofitted masonry wallet

Stress strain curve of URM, PP-band retrofitted, GFRP retrofitted and GFRP+PP-band retrofitted masonry wallets are shown in Figure 12. GFRP+PP-band retrofitted masonry wallet has not only increased the initial strength as that of GFRP retrofitted masonry wallet but also the ductility and %age strain as that of PP-band retrofitted masonry wallet. Final failure of masonry wallet has also become gradual and ductile. In addition to, application of GFRP+PP-band has also increased the residual strength of masonry wallet. Figure 13 shows the failure mechanism of GFRP+PP-band retrofitted masonry wallet.

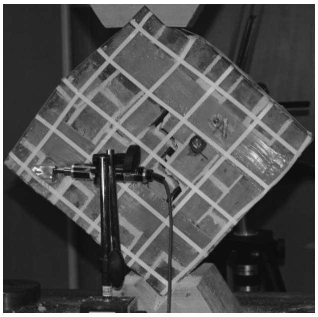

**Figure 13**. Failure Pattern of GFRP+PP-band retrofitted masonry wallet

## CONCLUSIONS.

Current study provides a very simple and clear stress strain analysis of different retrofitting methods. Each method has its strong points and weak points but proposed GFRP+PP-band composite retrofitting techniques is one the cost efficient and high performance composite retrofitting method which can be used for seismic retrofitting of masonry structures. GFRP is a cheapest type of FRP as compared to Carbon Fiber reinforced polymer and Aramid Fiber Reinforced Polymer. On the other hand PP-band is also one of the cheapest retrofitting materials. As a result, GFRP+PP-band composite is cost effective material which can increase the initial strength, ductility, deformation capacity and energy dissipation capacity. Failure of GFRP and GFRP+PP-band of wallets was started due to debonding of GFRP from the brick surface which motivates to use a strong epoxy agent rather than a strong FRP.

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